Comparative Analysis of Distortive and Non-Distortive Techniques for PAPR Reduction in OFDM Systems

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Abstract: **OFDM is a popular and widely accepted modulation and multiplexing technique in the area of wireless communication. IEEE 802.15, a wireless specification defined for WPAN is an emerging wireless technology for short range multimedia applications. Two general categories of 802.15 are the low rate 802.15.4 (ZigBee) and high rate 802.15.3 (UWB). In their physical (PHY) layer design, OFDM is a competing technique due to the various advantages it renders in the practical wireless media. OFDM has been a popular technique for many years and adopted as the core technique in a number of wireless standards. It makes the system more immune to interference like InterSymbol Interference (ISI) and InterCarrier Interference (ICI) and dispersive effects of the channel. It is also a spectrally efficient scheme since the spectra of the signal are overlapping in nature. Despite these advantages OFDM suffers from a serious problem of high Peak to Average Power. This limits the system's capabilities and increases the complexity. This paper compares the signal distortion technique of Amplitude Clipping and the distortionless technique of SLM for Peak to Average Power reduction.**

***Index Terms*—OFDM, PAPR, Clipping, SLM**

I. Introduction

The OFDM physical layer implements scalable spectrum efficiency to achieve high data rates with flexible radio coverage. OFDM modulation schemes offer many advantages for multicarrier transmission at high data rates over time dispersive channels, particularly in mobile applications. OFDM can reduce the ISI, delay spread of signal and increase the spectral efficiency of system. Due to the numerous advantages of this system, it has been successfully applied in wide variety of digital communications over the past several years and has been adapted to the wireless LAN standards as IEEE 802.11a/g. An OFDM signal consists of a number of independently modulated subcarriers, which can give a large peak-to-average power ratio (PAPR) when added up coherently. When N signals are added with the same phase, they produce a peak power that is N times the average power [6]. A large PAPR ratio brings disadvantages like an increased complexity of the analog-to-digital (A/D) and digital-to-analog (D/A) converters and a reduced efficiency of the RF power amplifier. To reduce PAPR various techniques have been proposed, which basically can be divided in three categories. First, there are signal distortion techniques, which reduce the peak amplitudes simply by nonlinearly distorting the OFDM signal at or around the peaks. Examples of distortion techniques are clipping, peak windowing, and peak cancellation. Second, there are coding techniques that use a special FEC code set that excludes OFDM symbols with a large PAPR ratio. The third technique scrambles each OFDM symbol with different scrambling sequences and selecting the sequence that gives the smallest PAPR ratio [6]. Fig.1 shows the block diagram of OFDM transceiver system.

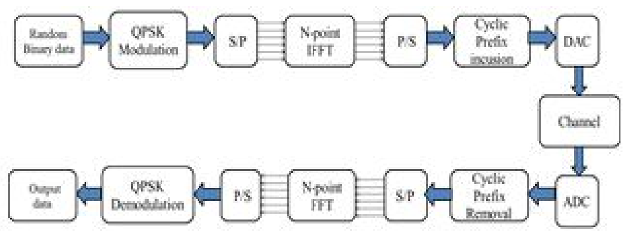

Figure 1. Block Diagram for OFDM Transceiver

II. Peak-to-average ratio

One of the major problems of OFDM signal is the large dynamic range of the signal. This amplitude fluctuation is expressed by a parameter called PAPR.

An OFDM signal consists of a number of independently modulated subcarriers, which can give a large peak-to-average power when added up coherently. When N signals are added with the same phase, they produce a peak power that is N times the average power [4]. A large PAPR ratio brings disadvantages like an increased complexity of the A/D and D/A converters and a reduced efficiency of the RF power amplifier. An OFDM signal is the sum of complex random variables, each of it can be considered as a complex modulated signal at a different frequency. Let us denote the collection of all data symbols X_k, k = 0, 1,…, N – 1, as a vector $X = [X_0, X_1 ..., X_{N-1}]^T$ which is a data block. N is the number of subcarriers. The complex baseband representation of a multicarrier signal consisting of N subcarriers is given by (1) which is nothing but DFT.

$$x(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j2\pi f_k t}, \quad 0 \le t < NT \qquad (1)$$

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Where f_k is a set of N orthogonal subcarrier frequencies, i.e. $f_k = k\Delta f$ and T is the symbol period.

Here an approximation will be made that only those samples of *x(t)* will be considered which are N times L, where L indicates an integer that is greater than or equal to 1. The vector representation of the L times oversampled time domain signal samples are $x = [x_0, x_1 .... x_{NL-1}]^T$ and obtained as

$$x_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{\frac{j2\pi nk}{NL}}, \; 0 \le n \le NL-1 \qquad (2)$$

where the sequence $\{x_n\}$ can be interpreted as the Inverse Discrete Fourier Transform (IDFT) of data block X with N times (L – 1) zero padding. It is well known that the PAPR of the continuous-time signal cannot be obtained precisely by the use of Nyquist rate sampling, which corresponds to the case of L = 1. It is shown in [7] that L = 4 can provide sufficiently accurate PAPR results. The PAPR computed from the L times oversampled time domain signal samples is given by (3)

$$PAPR = \frac{\max[\overline{x_n}\,\overline{x_n}^H]}{E[\overline{x_n}\,\overline{x_n}^H]} \qquad (3)$$

Where $\overline{x_n}$ is a complex valued column vector, *H* is Hermitian Transpose, E[.] is expectation operator and $0 \le n \le NL-1$.

III. Signal distortion technique

To reduce PAPR, there are signal distortion techniques, which reduce the peak amplitudes simply by nonlinearly distorting the OFDM signal at or around the peaks. Examples of distortion techniques are amplitude clipping, peak windowing, and peak cancellation. In this paper the effect of amplitude clipping has been simulated and analysed. Clipping is performed at the transmitter end after addition of CP as shown in fig. 2

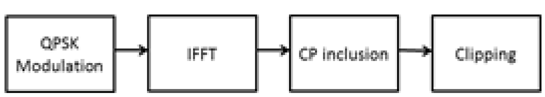

Figure 2. OFDM Transmitter with clipping

For simulation, following operations are performed at the Transmitter:

- Generate random binary data.
- QPSK Modulation of data
- Serial to Parallel conversion
- Inverse Fast Fourier Transform (IFFT)
- Inclusion of Cyclic Prefix
- Amplitude Clipping against a threshold
- Calculation of PAPR
- Pass through the fading channel
- Addition of AWGN noise

The following operations are performed at the Receiver:

- Removal of CP
- Fast Fourier Transform (FFT)
- Equalization using the channel transfer function.
- Extract the usable carriers
- Demodulation of data
- Binarize the demodulated data
- Calculation of BER
- Plot the BER Vs SNR.
- Plot the CCDF curve.

IV. Distortionless technique

In this technique scrambling of each OFDM symbol with different scrambling sequences is carried out and the sequence that gives the smallest PAPR ratio is selected. Examples of distortionless techniques are Partial Transmit Sequence (PTS), Selected Mapping (SLM) and Interleaving. In this paper the effect of SLM technique [1] has been simulated and analysed.

The fig.3 shows the block diagram for SLM.

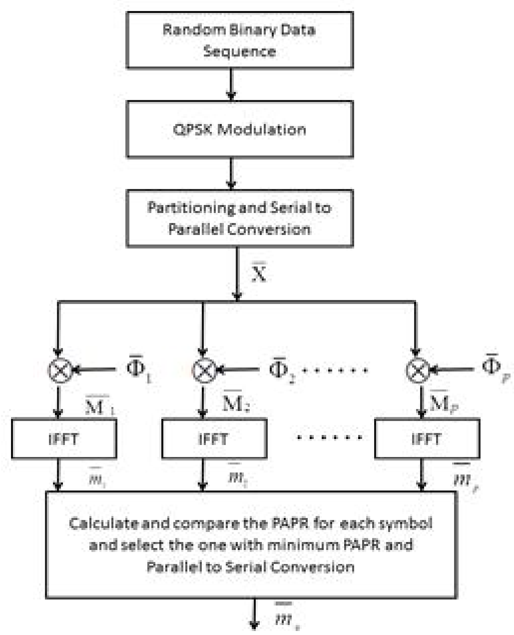

Figure 3. Block Diagram for SLM

The algorithm to implement SLM is as follows:

- Generate random binary data.
- QPSK Modulation of data
- Serial to Parallel conversion, such that the data is of the form

  $$\overline{X} = [x_1, x_2, ... x_N], \; \mathrm{N} = 64, 128, 256$$

- Generate phase sequence vectors as

  $\overline{\Phi}_p = [\Phi_{p,1}, \Phi_{p,2}, ..., \Phi_{p,N}], \; p = 1, 2, ...U$ Here U=64.

- Multiply the data vector with phase sequence vector to get the modified data block as

  $$\overline{M}_p = [x_1\Phi_{p,1}, \; x_2\Phi_{p,1}, ..., x_N\Phi_{p,N}], \; p = 1, 2, ...U$$

- Transform the signal in time domain by performing IDFT using IFFT algorithm.

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- Calculate PAPR for each modified data block.
- Select and transmit the data block with minimum value of PAPR.

V. Simulation results

The simulations have been carried out on MATLAB, for 10^5 bits and the modulation scheme used is QPSK. As a performance measure BER (Bit Error Rate) and CCDF (Complementary Cumulative Distribution Function) curves are used. The BER has been evaluated for Energy per bit to Noise ratio from 0 to 25 dB. For convergence of the plot Monte Carlo method is used for 100 iterations. Here an oversampling factor of L=4 is used which provides sufficiently accurate PAPR values [7].

The fig. 4 shows the CCDF plot for amplitude clipping implemented for different number of subcarriers, N=32, 64, 256. It can be observed that as the number of subcarriers (N) increases the peak power ratio increases. With respect to the curve for N=32, the PAPR for N=64 is increased by 0.5dB and for N=256 its 1dB.

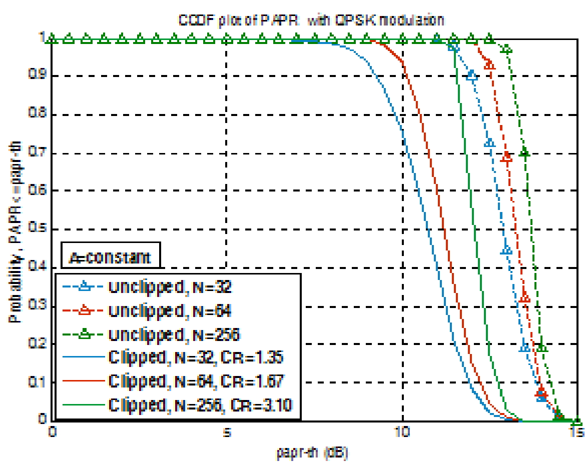

Figure 4. CCDF plot for Amplitude Clipping

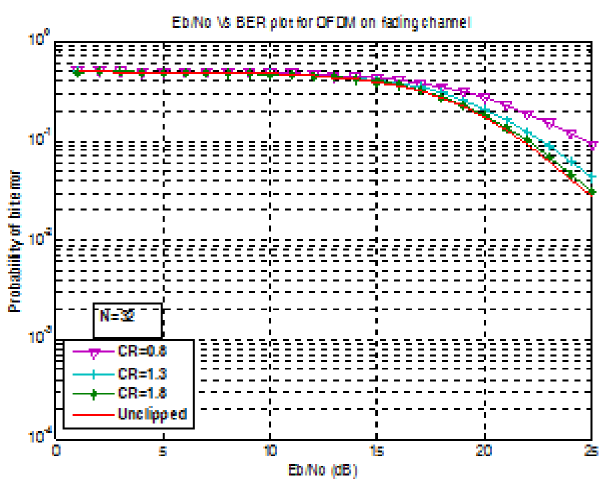

Figure 5. BER plot for clipping for N=32

The clipping ratio is defined as

$$CR = \frac{A}{\delta} \tag{4}$$

where A=clipping level and δ = rms value of signal.

Here, **A** for all the simulations has been taken constant, and it can be observed that as the number of subcarriers increases the clipping ratio also increases for the same level of amplitude clipping level.

The fig. 5 through 7 shows the BER plot for clipping implemented for N=32, 64 and 256 respectively.

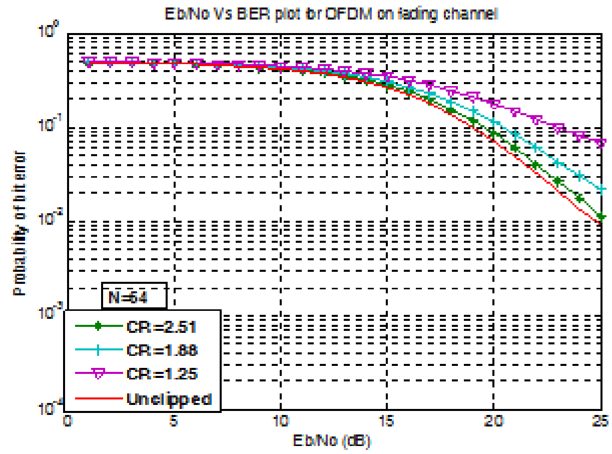

Figure 6. BER plot for clipping for N=64

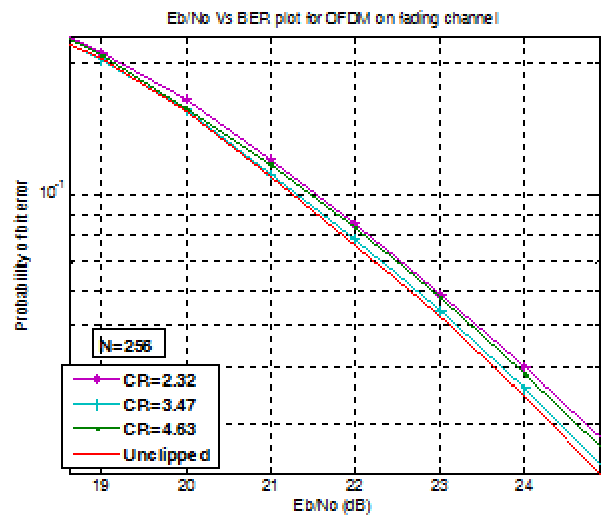

Figure 7. BER plot for clipping for N=256(magnified)

It can be observed from the BER plots for N=32, 64 that as the CR increases the BER performance gets better and close to the original unmodified signal.

In fig. 7, for N=256 it can be observed that for CR=3.47, BER degradation is very less and further increasing the CR beyond this value does not provide sufficient improvement in BER but degrades the BER much. So the CR should be selected judiciously. For N<256, the threshold for CR does not reach so quickly when compared to N>=256. The CR for all the three cases has been evaluated for the same level of amplitude clipping. The out of band emissions resulting from clipping is evident from fig. 8.

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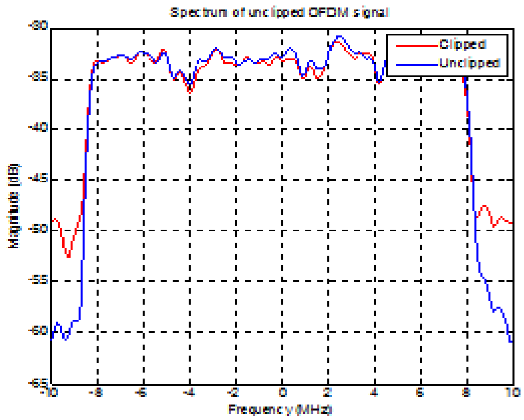

Figure 8. Power Spectral Density of Clipped OFDM signals

As the PAPR is a random variable, an adequate statistic is needed to characterize it. A common choice is to use the Complementary Cumulative Distribution Function (CCDF), which is defined as the probability of the PAPR exceeding a given threshold.

The plot in fig. 9 shows the CCDF curves for SLM technique simulated for N=64,128 and 256 subcarriers. The results are as expected, that for higher values o f N the PAPR also increases. The PAPR values in dB for the modified signal with N=64, 128 and 256 are 5, 7 and 9 respectively for a probability of 0.1.

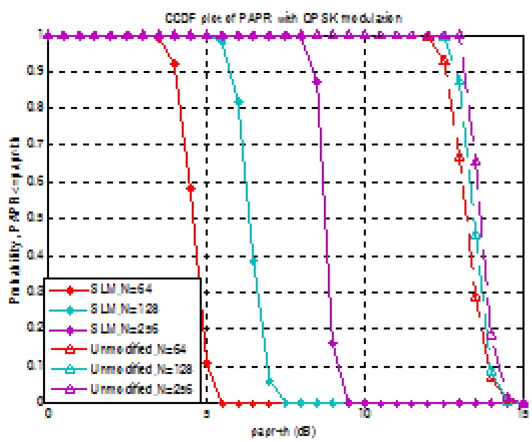

Figure 9. CCDF plot for SLM

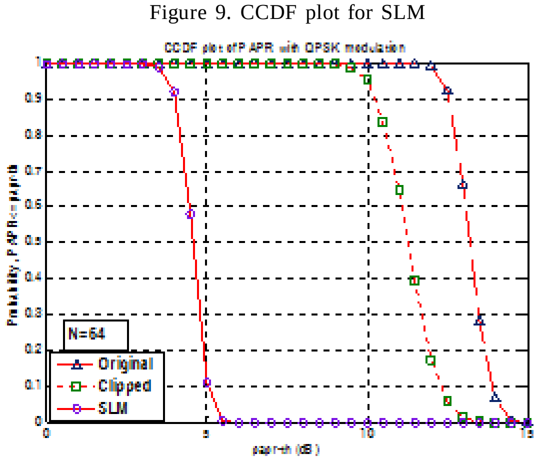

Figure 10. CCDF plot for comparison for N=64

The CCDF plot of fig. 10 shows the comparison of the two techniques. The reduction in the power ratio achieved by SLM is higher compared to clipping technique. The BER performance of SLM will be same as the original signal since the signal is not distorted in any way provided that the phase sequence used at the transmitter is known at the receiver end. Table-I gives the comparison between the two reduction techniques discussed.

Table I. Comparison

Parameters	OFDM	Clipping	SLM
BER	Low	High	Low
PAPR (dB)	12.93	10.85	4.32
Distortion	No	Yes	No
System Complexity	Low	Moderate	High
System Memory	Low	Low	High
PAPR reduction at the cost of	-	BER	Data Rate

Conclusion

Clipping technique causes out of band noise and spectral regrowth and has a drawback that it reduces PAPR at the cost of increase in BER. The increase in BER by nonlinear distortion requires more received power to maintain the desired BER, which might hamper the power savings from nonlinear amplification. In SLM, side information about the transmitted phase sequence need to be sent which is a drawback since it affects the data rate. SLM successfully works for any number of subcarriers. It can be seen from fig.9 that by clipping there is 2dB reduction in PAPR, while for SLM its 9dB when compared to the original OFDM signal. We will extend the work of reducing PAPR ratio by this method in the OFDM system under multiuser environment.

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